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METHOD AND APPARATUS FOR OPTICAL AMPLIFYING DEVICE GAIN CONTROL WITH GAIN THRESHOLD

PROVISIONAL APPLICATION

The present application claims priority under 35 U.S.C. § 119(e) of a provisional application 60/427,741, filed on November 20, 2002 the entirety of which is hereby incorporated by reference.

FIELD OF THE INVENTION

The field of the invention generally relates to optical amplifying devices. More particularly, the invention relates to optical amplifying devices and methods with gain control.

BACKGROUND OF THE INVENTION

Conventional optical amplifiers may be operated under variable control to achieve an amplifier response that is flat over a wide gain range. Amplifiers may also be operated in constant gain mode in which the pumps are controlled such that the amplifier gain is constant with the result being that the output power closely tracks the input power.

In optical systems, it is desirable to launch a constant power per channel into the fiber. This may be achieved by operating the amplifier in a constant gain mode. In constant gain mode, any change in the input power of a constant gain amplifier produces a proportional change in the output power of the amplifier. Thus any change in the input due to change in channel count (i.e. addition and deletion of channels), will cause a proportional change in the output power of the amplifier, keeping the per channel launch power nominally constant.

While this method is useful for tracking changes in channel count, there are drawbacks. The amplifier has no means of differentiating between changes in input power caused by channel count changes and other events such as change in fiber loss, component losses etc. While these changes may be small over a single span, these changes will accumulate along multiple sections of fibers and amplifiers to a detrimental effect.

Consider a chain 100 of optical amplifiers 102-X shown in the block diagram of Figure 1. The input power per channel to the first amplifier 102-1 is P1. The average losses of the fiber sections 104-1 to 104-N are shown as L_1, L_2, ... L_N. If the launch power per channel is assumed to be same at each fiber section (and same as at the output of the first amplifier), the

gains G_2, ... G_N of the amplifiers 102-2 ... 102-N track the average loss of the fiber section preceding the amplifier (L_1, L_2 ... L_N). The time dependent variation in fiber loss given by ΔL_1, ΔL_2, ... ΔL_N and the variation in input power is assumed to be ΔP_1.

As noted above, conventional optical amplifiers operate in a simple constant gain mode. In this case, the control circuitry keeps the gain of the amplifier at target value G_{CG}. A control mechanism for the conventional amplifier in constant gain mode is shown in the flow chart 200 of Figure 2. In Figure 2, P_{in} is the input power to an amplifier, and P_{out} is the output power from the amplifier. It is assumed that the power values are in a logarithmic scale for ease of calculation.

In step 210, the target gain G_{CG} for the amplifier is set. This value is provisioned in the constant gain mode and typically corresponds to the gain of a particular stage or multiple stages of the chain of amplifiers. In step 220, input and output powers P_{in} and P_{out} are measured and the actual gain G_{meas} is calculated from the measured power values. Step 230 determines whether or not a deviation G_{error} from the target gain G_{CG} exists. If so, the amplifier's output P_{out} is adjusted by G_{error} in step 240 and the method returns to step 220. If the

deviation is determined not to exist in step 230, the output is not adjusted and the method returns to step 220.

Figure 3 graphically illustrates the tracking of the output power of the amplifier as a function of the input power. The amplifier is assumed to be operating at a target set gain of 25 dB. As shown, the output power of the amplifier tracks the input as closely as possible.

It can be seen that substantial output power variations occur if the constant gain control is utilized. Such power fluctuations accumulate over a chain of amplifiers to a detrimental effect as pointed out above.

BRIEF DESCRIPTION OF THE DRAWINGS

Features of the present invention will become more fully understood to those skilled in the art from the detailed description given hereinbelow with reference to the drawings, which are given by way of illustrations only and thus are not limitative of the invention, wherein:

Figure 1 is a block diagram illustrating a chain of conventional constant gain mode optical amplifiers;

Figure 2 is a flow chart illustrating a control mechanism of a conventional constant gain optical amplifier;

Figure 3 is a graphical illustration of tracking of input to output of a conventional constant gain optical amplifier;

Figure 4 is a block diagram illustrating an exemplary control mechanism of an optical amplifying device according to an embodiment of the present invention;

Figure 5 is a block diagram of an optical amplifying device according to an embodiment of the present invention;

Figure 6 is a flow chart illustrating an exemplary control mechanism of an optical amplifying device according to an embodiment of the present invention;

Figure 7 is an exemplary graphical illustration of power output of an optical amplifying device according to an embodiment of the present invention; and

Figure 8 is a block diagram of an EDFA optical amplifying device according to an embodiment of the present invention.

DETAILED DESCRIPTION

For simplicity and illustrative purposes, the principles of the present invention are described by referring mainly to exemplary embodiments thereof. The same reference numbers and symbols in different drawings identify the same or similar elements. Also, the following detailed description does not

limit the invention. The scope of the invention is defined by the claims and equivalents thereof.

As noted previously, a simple constant gain mode amplifier amplifies not only the desired input signal, but also amplifies the accumulated imperfections of the optical system.

Such imperfections in the input signal generally occur slowly over time and typically are low in magnitude (also known as signal drift or simply "drift"). For example, variations in span losses and variation in laser powers used for inputting signals to the amplifiers can occur due to polarization dependence of optical components. Also, mechanical and/or thermal effects can cause time dependent loss variations in optical fibers. Another source of noise that can couple into the system include any noise that can couple into the amplifier pump electronics and consequently into the amplifier output.

While all of these variations are usually fairly small, it is desirable that these variations are squelched at each amplifier and not allowed to accumulate along the system. For example, in order to minimize any noise coupling into the pump, it is desirable to operate the pumps using a constant current drive for the pumps.

Figure 4 is a high level block diagram 400 of a control mechanism of an exemplary optical amplifying device of the present invention. As shown, the optical amplifying device operates in one of two modes - constant power mode 410 (gain threshold mode) or constant gain mode 420 (gain control mode). The explanation is as follows.

As noted above, variations in the power of the input to the amplifying device that is relatively small in magnitude are more likely due to the imperfections in the system rather than variations in the actual input signal. In this type of a situation, it is desired that the amplifying device be suppressed from reacting to the input variations. By operating the optical amplifying device in the constant power mode 410, the suppression may be achieved. In the above constant power mode can mean both constant output power or constant pump power (by delivering constant pump current to pumps). For example, natural erbium doped fiber amplifier (EDFA) behavior may be utilized to suppress any low frequency, low magnitude changes to the input.

Conversely, large variations in power are more likely due to the changes in the actual input signal itself. For example, adding or dropping channels of a wavelength division multiplexed

(WDM) signal will typically cause a large power variation. Switching operations may cause large power variation as well. Under this type of a circumstance, it is desired that the amplifying device track the input. By operating the optical amplifying device in the constant gain mode 420, tracking may be achieved.

The optical amplifying device may switch from one mode to another appropriately through the use of a gain threshold. For example, assume that the optical amplifying device is currently operating in the constant power mode 410. An actual gain $G_{MEAS} = P_{OUT} - P_{IN}$ may be determined from the output and input powers of the amplifying device. Then, the gain error $G_{ERROR} = G_{CG} - G_{MEAS}$ (where G_{CG} is the target gain) may be determined. If the absolute value of G_{ERROR} exceeds a predetermined threshold value G_{TH}, i.e. if $|G_{ERROR}| - G_{TH} > 0$, then the amplifying device may switch to the constant gain mode 420 (arrow 430 in Figure 4). Otherwise, the amplifying device may remain in the constant power mode 410 (arrow 440). The constant power mode 410 may also be described as constant power with gain threshold mode or simply "gain threshold mode."

In an embodiment of the present invention, the optical amplifying device operates in constant gain mode 420 for a brief

lock out period (10 seconds for example) and returns to back to gain threshold (CP) mode 410. It should be noted that the lock out period may be set at any period appropriate for the situation.

If no transient events occur during the lock out period, then the optical amplifying device may be switched to operate in the gain threshold mode (i.e. gain threshold can be re-enabled) 410 (arrow 450). In an embodiment, the transient event may be defined as the output power of the amplifying device deviating from a reference power level by more than a preset amount within prescribed time, such as the lock out period. In another embodiment, the transient event may be defined as the level of the output power fluctuating by more than a preset amount within the prescribed time. In general, the transient event is an indication that the output of the amplifying device is in a state of flux and the optical system has not reached a desired stability.

If one or more transient events do occur, which indicates that the optical system has not stabilized, then the lock out period may be reset and the optical amplifying device may remain in the constant gain mode 420 (arrow 460).

Other criteria can also be used to return the optical amplifying device to the gain threshold mode. For example, instead of detecting transient events as described above, an alternative may be simply set the lock out at a "long enough" period and return to the gain threshold mode after the lock out period without regard to transient events occurring. However, it is preferred that the optical amplifying device be returned to the gain threshold mode after determining that the optical system has stabilized.

Figure 5 is a block diagram of an optical amplifying apparatus 500 according to an embodiment of the present invention. The apparatus includes an optical amplifying device 510, a controlling device 520, and a measuring device 530. The optical amplifying device 510 receives input signal and outputs an output signal. The measuring device 530 is configured to measure power levels on a plurality of points within the optical amplifying device 510 including input and output power levels P_{IN} and P_{OUT}. Both the optical amplifying device 510 and the measuring device 530 communicate with the controlling device 520.

The controlling device 520 controls the operation of the optical amplifying device 510 based on the power levels measured by the measuring device 530. The controlling device 520

controls the optical amplifying device 510 to operate either in the gain threshold mode (410 of Figure 4) or the constant gain mode (420 of Figure 4).

As an example, in the gain threshold mode, the controlling device 520 calculates the actual gain of the optical amplifying device 510 based on the input and output power levels P_{IN} and P_{OUT} - more specifically, the gain may be determined as $P_{OUT} - P_{IN}$ (logarithmic scale). If the absolute value of the gain error does not exceed a preset threshold, then the controlling device 520 adjusts the gain of the optical amplifying device 510 so that output power level P_{OUT} is substantially equal to a preset level.

In the constant gain mode, the controlling device 520 determines whether or not a transient event occurred within a lock out period. If so, the controlling device 520 continues to operate the optical amplifying device 510 in the constant gain mode and resets the lock out period.

The controlling device 520 also switches the mode as necessary. As an example, the controlling device 520 switches the operation of the optical amplifying device 510 from the gain threshold mode to the constant gain mode when the absolute value of the gain error of the optical amplifying device 510 exceeds

the preset gain threshold. The controlling device 520 switches the operation from the constant gain mode to the gain threshold mode if it determines that no transient event occurs within the lock out period.

Figure 6 is a flow chart illustrating an exemplary control mechanism of an optical amplifying device according to an embodiment of the present invention. In step 610, target gain G_{CG} and threshold gain G_{TH} are set. In step 620, the optical amplifying device enters the gain threshold mode. In this step, input and output powers P_{IN} and P_{OUT} are measured and the gain $G_{MEAS} = P_{OUT} - P_{IN}$ is determined. In step 630, the gain error $G_{ERROR} = G_{CG} - G_{MEAS}$ is determined and compared against the threshold gain G_{TH}.

If the absolute value of the gain error G_{ERROR} exceeds the threshold gain G_{TH}, then the constant gain mode is entered (see step 640). In step 640, the input power P_{IN} the optical amplifying device is appropriately amplified by G_{CG} and output as P_{OUT}. The optical amplifying device remains in the constant gain mode as long as one or more transient events occur within a preset lock out period as described above (see step 650). If no transient event occurs within the lock out period, then the

optical amplifying device enters the gain threshold mode (see step 620).

If the absolute value of the gain error G_{ERROR} is within the threshold gain G_{TH} in step 630, then the optical amplifying device remains in the gain threshold mode.

Figure 7 is an exemplary graphical illustration 700 of power output of an optical amplifying device utilizing the gain threshold described above. In this non-limiting example, the target gain G_{CG} for the amplifying device is set at 25 dB and the gain threshold G_{TH} is set at 0.2 dB. It should be noted that the target gain G_{CG} and the gain threshold G_{TH} are not limited to the above values and may be set to any values as deemed appropriate.

In the gain threshold mode, for example between time t_0 and t_1, the gain of the optical amplifying device varies according to the input power so that the output power P_{OUT} is substantially constant.

When the absolute value of the gain error G_{ERROR} exceeds the threshold G_{TH}, i.e. when $|G_{ERROR}| - G_{TH} > 0$ becomes true, the optical amplifying device enters the constant gain mode, for example between times t_1 and t_2 and between times t_3 and t_4.

During these times, the output power P_{OUT} is appropriately amplified as shown.

Assuming no transient events occur, the optical amplifying device reenters gain threshold mode, for example between times t_2 and t_3 and beyond time t_4.

As shown, during gain threshold mode, the gain is adjusted to provide the output power P_{OUT} at a substantially constant level. During the constant gain mode, the gain is kept substantially constant so that output power P_{OUT} tracks the input power P_{IN}.

An optical amplifying devices may include a service channel, one or more variable optical attenuators (VOA), signal monitors, optical monitors, input isolator, output isolator, output back reflection monitor, gain flattening filter, pumps, on-board electrical control circuits including communication port, etc. Figure 8 is a block diagram of a three stage optical amplifying device 800 according to an embodiment of the present invention. For example, the amplifying device 800 may include EDFA amplifiers. Of course, it should be noted that the EDFA is but one of several amplifiers made of optically active materials that may be used. In addition, erbium doped waveguide amplifier (EDWA) may be used as well.

The device 800 includes various power monitoring points as shown that are monitored by the measuring device (see Figure 5). The device 800 may include first, second, and third optical amplifier stages 810-1, 810-2, and 810-3 connected in series fashion. The device 800 may also include a VOA 820 and connected as shown. The VOA 820 may be manipulated to control the gain of the device 800. While not shown, it should be noted that other VOAs may be added to finely tune the operation of the device 800.

The device 800 may also include an optional dispersion compensation fiber (DCF) 830. The DCF is desirable to provide periodic dispersion compensation for high frequency signals, typically 10Gb/s or higher.

In general, an optical amplifying device may include a plurality of amplifier stages connected in series, one or more VOAs connected in series with the plurality of optical amplifier stages such that each VOA receives an output of one optical amplifier and outputs to a next optical amplifier. At least least one VOA is controlled by the controlling device. In addition, the optical amplifying device may include one or more DCFs, with each DCF receiving an output of an amplifier and outputting to a next amplifier.

A simpler implementation of an optical amplifying device would include one or more amplifier stages and a VOA. The gain of the amplifier may be controlled by adjusting the VOA. Alternatives include adjusting power supplied by the pump(s) and by controlling other VOA(s) of the amplifier.

While the invention has been described with reference to the exemplary embodiments thereof, it is to be understood that various modifications may be made to the described embodiments without departing from the spirit and scope of the invention thereof. The descriptions used herein are set forth by way of illustration only and are not intended as limitations.